09/351199

COMPOSING A REALIGNED IMAGE

ABSTRACT OF THE INVENTION

This invention provides methods, apparatus and article of manufacture used as a countermeasure to image distorting. The present invention involves automatically detecting the presence of distortion in a presumed distorted image, measuring the magnitude and type of distortion, and finally creating a realigned image. Once image distortion is removed, conventional invisible watermark extraction methods are employed to extract the watermark from the realigned image. The automatic method does not depend on a process of visually examining a composite image and recording the coordinates of pixel locations closest to common image features in a distorted image and reference image. Generally, the presumed distorted image is resized to the same size as the reference image. Reference centers at at least three distinct points that do not form a straight line are selected. At each reference center, a sub-image is excised. Pairs of sub-images, one excised from the reference image and the other excised from the distorted image, having the same reference center are used in the process of removal of the distortion.

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PRIORITY

The present application claims priority of Provisional Application, Application Number 60/117,866, having the same title and a filing date of 01/29/99, by inventors Gordon Braudaway et al.

CROSS REFERENCES

Sub B1

~~The present application is related to the following~~ applications even dated with the above referenced Provisional Application: Application Number 09/240,242, entitled, "Recovering Invisible Digital Image Watermarks From Distorted Images," by inventors Gordon Braudaway et al.; and Application Number 60/117,921 entitled, "Watermarking and Determining Distortion in an Image," by inventors Gordon Braudaway et al., which ~~are incorporated herein by reference in their entirety.~~

FIELD OF THE INVENTION

This application relates to the field of digitized imaging. It is more specifically directed to determining and removal of image distortion from an image.

BACKGROUND OF THE INVENTION

With the development of means of production and circulation of digital images, and the means of imbedding relatively invisible watermarks into digital images ostensibly to convey ownership of the image, there is now financial incentive to attack an imbedded watermark in an attempt to render it non-extractable. Pixel locations of a watermarked image are presumed to correspond to those in an unmarked original image. Generally, the watermark is imbedded by altering only the values of the pixel components of the original image, not their geometric positions. This may be accomplished employing such methods as described in US Patent 5,825,892 which is incorporated herein by reference in its entirety.

Some methods of attacking an imbedded watermark rely on constructing a new image that is a geometrically

distorted copy of the watermarked image. This new image is herein referred to as a **distorted copy.** Pixels in the distorted copy are placed at subtly distorted positions relative to those in the watermarked image. Pixel component values in the distorted copy are determined by two-dimensional interpolation of component values of enclosing pixel in the watermarked image. No constraints can be placed on the types of pixel position distortion an attacker might choose to use. To those skilled in the art, however, it is obvious that excessive pixel position-distortion will cause the distorted copy to be a caricature of the watermarked image, thus diminishing or destroying its economic value. Whether a distortion is excessive is a subjective measure. For a distorted copy to be useful, it requires that linear or nonlinear distortion methods that are used by an attacker have to be used sparingly and in such a manner as to produce smoothly varying and relatively small position distortions. This is so as to be essentially unobjectionable and casually unnoticeable to untrained observers. The human visual system, as a qualitative measuring device, can be relied upon to readily detect excessive distortion. It is desirable to have a method of defense that requires little or no limits to be placed on pixel position-distortions produced by the attacking method.

SUMMARY OF THE INVENTION

In one aspect, the present invention provides a method, apparatus and article of manufacture employing an undistorted reference image relative to which measurements of distortion are made. These employ an automatic method for composing a **realigned** image which does not depend on a process of visually examining a **composite image**, and recording the coordinates of pixel locations closest to common image features in a **distorted image** and **reference image.** If the presumed **distorted image** is not the same size as the **reference image**, it is made so by shrinking or enlarging the **reference image.** At the next step, at least three distinct points that do not form a straight line are selected. The integer coordinates of the pixels nearest these points are herein referred to as **reference centers.** At each reference center, a segment of each image, herein referred to as a sub-image, is excised, thus producing for each image as many sub-images as there are distinct points. The horizontal and vertical dimensions of the sub-images, in integer pixel coordinates, are respectively based on the common horizontal and vertical dimensions of the images. A pair of sub-image, one excised from the **reference image** and the other excised from the **distorted image,** having the same reference center are manipulated to determine and/or substantially remove the distortion from the distorted image.

Another aspect of the present invention enables a digital image watermark to be extracted from a geometrically distorted copy of a reference image.

Other aspects and a better understanding of the invention may be realized by referring to the Detailed Description.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features, and advantages of the present invention will become apparent upon further consideration of the following detailed description of the invention when read in conjunction with the drawing figure.

DESCRIPTION OF THE INVENTION

The present invention provides a method, apparatus and article of manufacture by which the distortion in a distorted copy of an image is automatically measured and removed sufficiently well that a relatively invisible image watermark extraction is possible. In an embodiment of the invention, the method employs a **reference image** relative to which measurements of distortion are made. For example, an original unmarked image or a relatively invisibly watermarked copy of the

original image, called a watermarked image, serve equally well as the reference image.

The automatic method composes a **realigned image** in a way that does not depend on a process of visually examining a **composite image** and recording the coordinates of pixel locations closest to common image features in a **distorted copy** and **reference image**, as is the case in the semiautomatic method of Application Number 09/240,242, cross-referenced herewith.

As with the semiautomatic method, if the presumed **distorted copy** is not the same size as the **reference image**, it is made so by shrinking or enlarging the **distorted copy** using a method such as pixel interpolation or pixel extrapolation. The distorted copy, after being geometrically resized, is herein referred to as a **geometric alteration.** There are well known automatic and manual methods for resizing images.

At the next step, the automatic process differs from the semiautomatic process. At least three common pixel locations in the two images, herein referred to as **reference centers**, not lying in any straight line are required for the automatic method of this invention. In an example embodiment, a coarse but regularly spaced simulated mesh is superimposed identically on each of the two images. Each knot in the mesh forms one of the common pixel locations. The integer coordinates of the pixels nearest each of the at least three common pixel

locations are the **reference centers.** At each reference center, a segment of each image, herein referred to as a sub-image, is excised, thus producing for each image as many sub-images as there are common pixel locations. The horizontal and vertical dimensions of the sub-images, in integer pixel coordinates, are based on the common horizontal and vertical dimensions, respectively, of the images. The pair of sub-images, one excised from the **reference image** and the other excised from the **geometric alteration,** having the same reference center are herein referred to as **corresponding sub-images.** A typical embodiment employs three common pixel locations.

When the geometric alteration is laid upon the reference image, the intersection of pixels in the reference image with pixels in the geometric alteration is an area of each image called the **safe area.** Although initially the safe area is the entire area of the geometric alteration and the reference image, on subsequent iterations of this realignment method the safe area may be smaller than the reference image. Each sub-image is centered at its respective reference center. If any pixel of a sub-image extends beyond the boundaries of the safe area, such as at the edges of the safe area, then the top or bottom edge of the corresponding sub-images, and the left or right edge of the corresponding sub-images, if also necessary, are repositioned. The two subimages, in unison, are repositioned vertically and horizontally by the minimum

number of pixel locations necessary so that no pixel of either sub-image lies in whole or in part outside of the safe area. The corresponding reference center is adjusted to lie at the center of the repositioned sub-images. Reference centers, after this adjustment process, are referred to as **adjusted centers**, whether they were adjusted or not. Note that in the case where the sub-image horizontal width, I, and vertical height, J, are even integers, such as powers of two, and the coordinates of the sub-images are indexed 0 to $I-1$ and 0 to $J-1$, respectively, the integer coordinates of the center of each sub-image are defined to be $I/2$ and $J/2$. Also note that I should be less than the width and J should be less than the height of the reference image and the geometric alteration.

The n-th pair of sub-images, one from the reference image designated the n-th reference sub-image and a corresponding one from the geometric alteration designated the n-th distorted sub-image, is used to compute a two-dimensional cross-correlation surface relating the distorted sub-image with the reference sub-image image. Those skilled in the art will recognize that there are many methods that may be used to compute or approximate a cross-correlation surface relating the two corresponding sub-images. Regardless of the method used, any method that produces the intended result of determining the horizontal and vertical offsets of the distorted sub-image relative to the reference sub-image that achieves a good match may

be employed. For example, a good match has offsets that can not be improved by more than the spacing of 1.5 pixels in any direction by using any other means of pattern matching. A better match is readily achievable if the distortions are generally linear. Watermark detection seldom requires a match better than a 0.5-2.0 pixel spacing. If required, more complex iteration techniques may be used to achieve a best match.

In an example embodiment, forward and inverse discrete Fast Fourier Transforms (FFT's) are used to compute a cross-correlation surface. Note that for methods using FFT's, all sub-images are converted to monochrome, if not already so. The non-integer interpolated horizontal and vertical offsets of the peak of the cross-correlation surface, p_n and q_n, relative to the origin of the cross-correlation surface are used as additive offsets relating the center of the n-th distorted sub-image relative to the n-th corresponding adjusted center. Thus, for each pair of sub-images, the coordinates of the adjusted center are the center on the n-th reference sub-image. The sums of the coordinates of the adjusted center plus the offsets of the peak of the n-th cross-correlation surface become the approximate coordinates of the center of the distorted sub image, $u_n = x_n+p_n$ and $v_n = y_n+q_n$. The coordinates of the offset center of the distorted sub-sub image and the adjusted center, herein referred to as computed pixel coordinates, are analogous to the measured pixel coordinates of common features visually

selected from the geometric alteration and reference image of the previously cited semiautomatic method. Using the computed pixel coordinates instead of the measured pixel coordinates, the coefficients matrix, **A**, of the pixel position interpolation equations are computed, as in the semiautomatic method.

In another example embodiment, forward and inverse discrete Fast Fourier Transforms (FFT's) are used to compute a modified cross-correlation surface. The magnitudes of the Fourier transform coefficients are modified to make said magnitudes uniform. An inverse Fourier transform is used to compute the modified cross-correlation surface.

In yet another example embodiment, a weighted sum of the ordinary and modified Fourier transform coefficients is formed before using an inverse Fourier transform to compute a weighted cross correlation surface.

In an embodiment of the automatic method, use of a statistical screen is incorporated into the next step. Use of a statistical screen is generally not needed in the semiautomatic method. Because the selection of sub-images is done indiscriminately, it is possible that some sub-images may have few features (or even none). The cross-correlation surfaces computed from such sub-images may be relatively flat and have a misleading peak. An additional test is used to

discriminate against statistical out-flyers that can occur from such misleading peaks. As used herein, an 'out-flyer' is a value from a set of values that deviates so greatly from the other values in the set that it is statistically unlikely to be a member of the set.

An example statistical screen discriminating against out-flyers is embodied as follows. Each of the pairs of computed pixel coordinates, u_n and v_n, is processed by the interpolation equations to give a **proposed reference center**, x_n' and y_n'. The Euclidean distance between the proposed reference center and the corresponding adjusted center, x_n and y_n, is computed for each of the n sub-images. Out-flyers are deleted from the set of n Euclidean distances, largest first, based on their value being above a first threshold value. If any out-flyer is deleted, the offset center of its corresponding distorted sub-image and adjusted center are also deleted. The coefficients, **A**, are recomputed using the undeleted pairs of pixel coordinated, but never with fewer than three pairs of pixel coordinates.

From this point on, the automatic and semiautomatic methods generally parallel one another. The square submatrix, $\mathbf{S}_A$, of four of the coefficients of the interpolation equations is factored into four primitive image manipulation matrices. The **geometric alteration**

is manipulated by the four primitive image manipulations to form the **reoriented image.**

The entire restoration process is advantageously repeated iteratively by substituting the previously reoriented image for the geometric alteration before each subsequent iteration. For the automatic method, it has been found that for images with significant distortion, as many as three iterations are warranted. For attacks with more nonlinear distortion, additional iterations may be used to further improve reorientation of the **geometric alteration**. The iteration process is terminated when examination of the Euclidean distances shows that the reduction of all Euclidean distances relative to those from the previous iteration is less than a second threshold. Finally, the **reoriented image** is realigned left or right and up or down relative to the **reference image**, based on the offset coefficients **c** and **f** from the interpolation equations, to form the **realigned image**.

An overview of the steps of an example automatic realignment of a presumed distorted copy is shown in the figure. First, if the presumed **distorted copy** is not the same size as the **reference image**, it is shrunk or enlarged to make it the same size using any image resizing method; the resized **distorted copy** is herein referred to as the **geometric alteration**, (102).

In a particular embodiment, a common coarse but regularly spaced mesh having n knots is superimposed on both of the images, (104). The knots of the mesh serve as reference points for each of the images. A list of the horizontal and vertical coordinates, x_n and y_n, of pixels lying closest to the knots of the mesh is built; these coordinate pairs are herein referred to as the **reference centers**, (106). A **sub-image**, having dimensions I and J and centered at each of the **reference centers**, is excised from each of the images and converted to monochrome, if not already so, (108), producing n corresponding pairs of sub images. A safe area is determined as the intersection of pixels common to the geometric alteration and reference image (110). If any part of any **sub-image** lies beyond the boundaries of the safe area, it is repositioned left or right and up or down a minimum number of pixel locations until both it and its **corresponding sub-image** lie within the boundaries of the safe area, and their common reference center is adjusted to again lie at the center of the repositioned sub-images, (112). A two-dimensional cross correlation surface is computed from each of the n pairs of sub-images, (114). The non-integer horizontal and vertical **coordinate offsets**, p_n and q_n, of the greatest peak on each of the n cross-correlation surfaces are determined by two-dimensional interpolation, (116). The **distorted reference centers** are computed by adding the **coordinate offsets** to their corresponding **adjusted centers**, (118). Using the **adjusted centers** and the **distorted reference centers** in

stead of the manually measured pixel coordinate pairs, as in the referenced semiautomatic method, the coefficients matrix, **A**, of the pixel position interpolation equations is computed, (120), in a manner identical to that used in the cross-referenced semiautomatic method.

In this embodiment, the automatic method differs from the cross-referenced semiautomatic method in at least the next steps. Using the pixel position interpolation equations, each of the **distorted reference centers** is converted to form a **proposed reference center.** The Euclidean distance between each of the **proposed reference center** and its corresponding **adjusted center** is computed. Those that are "out-flyers", for example those greater than a first threshold, say a spacing of 5 pixels, are discarded while at least three are always retained, (122). If any of the **distorted reference centers** is discarded, (124), steps (120) through (124) are repeated using only the not-discarded adjusted centers and the not-discarded distorted reference centers. Otherwise, as in the referenced semiautomatic method, the square submatrix, $\mathbf{S}_A$, of four of the coefficients is factored into four primitive image manipulating matrices, (126), and the **geometric alteration** is manipulated by the four primitive image manipulations to form the **reoriented image**, (128).

If any of the primitive manipulations is not sufficiently small, as determined by comparing the

incremental changes of the not-discarded Euclidean distances to a second threshold, (130), the **geometric alteration** is replaced by the **reoriented image**, (132), and steps (104) through (130) are repeated. Otherwise, the **reoriented image** is offset according to the computed horizontal and vertical offset values to form the **realigned image**, (134). Often, an attempt is made to extract the invisible watermark from the **realigned image**, (136).

It is noted that the foregoing has outlined some of the more pertinent objects and embodiments of the present invention. This invention may be used for many image or image-like applications. Thus, although the description is made for particular arrangements and methods, the intent and concept of the invention is suitable and applicable to other arrangements and applications. It will be clear to those skilled in the art that modifications to the disclosed embodiments can be effected without departing from the spirit and scope of the invention. The described embodiments ought to be construed to be merely illustrative of some of the more prominent features and applications of the invention. Other beneficial results can be realized by applying the disclosed invention in a different manner or modifying the invention in ways known to those familiar with the art.